Exploration of CO_2 Emissions from Land-based Transport throughout Kabul City

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***ABSTRACT*:** Much of the transportation infrastructures in Afghanistan have either been damaged or have deteriorated due to lack of regular maintenance over decades. After the repatriation of Afghan refugees from neighboring countries, the population raised up rapidly, mostly in unplanned urban areas in Kabul city. This rapid increase in unplanned urban population has resulted in an increase in consumption patterns and a higher demand for transport, energy and other infrastructure, thereby putting a load on the pollution problem. While developed countries are trying to reduce car dependency on the back of low carbon objectives, the ownership and the use of private cars in urban areas of Kabul city is increasing dramatically. The slow growth of road infrastructure and high growth of vehicles imply that Kabul roads are reaching a saturation point in utilizing the existing capacities, hence, leading to congestion and further contributing to air pollution.

This paper explores the distribution and underlying the factors of CO_2 emissions per kilometer of each trip from land-based transport throughout Kabul city. The travel time and other related data collected by the authors in 2013 are used to examine the general travel patterns including travel time and traffic volume. Then we explore the distribution of CO_2 emissions throughout Kabul city from land-based transport. Finally, various measures are examined for the reduction of CO_2 emissions.

KEYWORDS: Transport CO_2 emissions, Travel time

1. INTRODUCTION

Kabul city is the most populous and urbanized area of Afghanistan with an estimated population of 3.95 million. The city's population grew from 1.96 million in 2000 to 2.99 million in 2005, reaching the growth rate as high as 8.44, but it is later slowed to 4.41 from 2005 to 2010, and to 4.26 from 2010 to 2015. Because of wars for several decades, Kabul suffered damage and destruction of its transportation facilities including pavements, sidewalks, traffic circles, drainage systems, traffic signs and signals, trolley buses, and almost all of the public buses. From 2001 to present, a rapid increase in population in planned and unplanned areas caused an increase in the number of motor vehicles and spurred the demand for transportation facilities and services. There are sidewalks on both sides of the streets in Kabul but those located in downtown (Districts 1 and 2) have capacities less than the pedestrian demand. Even more some shopkeepers and vendors have decreased the capacities by putting their merchandise along the sidewalks. These situations force people to walk alongside the street and occupy a significant portion of roadway capacity. Roundabouts are very common and about 35 of them exist. There are no left-turn and right-turn lanes even in the busiest streets. Even the newly-built multilane expressways have none of the lanes with road stripe, sufficient signs, and signals. Though recently, most of the intersections are signalized, but due to lack of appropriate data most of the signals are not activated and just a small number of them are activated full day or at a portion of the day. The on-street road occupancy, lack of proper places for bus stations, and also lack of signage and multiple modes sharing within the city decrease road capacity and increases delays and accidents due to the physical occupation of the space.

Fig.1.1 illustrates one of the challenges of multiple modes and on-street occupancy sharing the right-of-way in Kabul. As shown in Fig.1, motor vehicles, bicycles, motorcycles, pedestrians, and pushcart selling vegetables all share the road. The street vendors are especially problematic because they attract customers, leading to a reduction in road capacity.

Fig.1.1 Typical Kabul downtown street (Field survey 2013)

Road traffic activity and emissions from vehicles is an important immediate source of air pollution in the city of Kabul. The transport sector faces challenges of illegal import of used vehicles, continued use of very old and poorly maintenance vehicles (some vehicles are more than 60 years old), passenger and cargo overloading of vehicles, poor quality of transport fuel, limited road capacity, and long travel times leading to air pollution.

The vehicle fleet in Kabul city is dominated mostly by small cars and taxis. A vehicle census of Kabul in 2005 registered a total of 341,047 vehicles mostly small cars (66.2%), followed by trucks. The vehicle population is estimated to increase by approximately 11% annually.

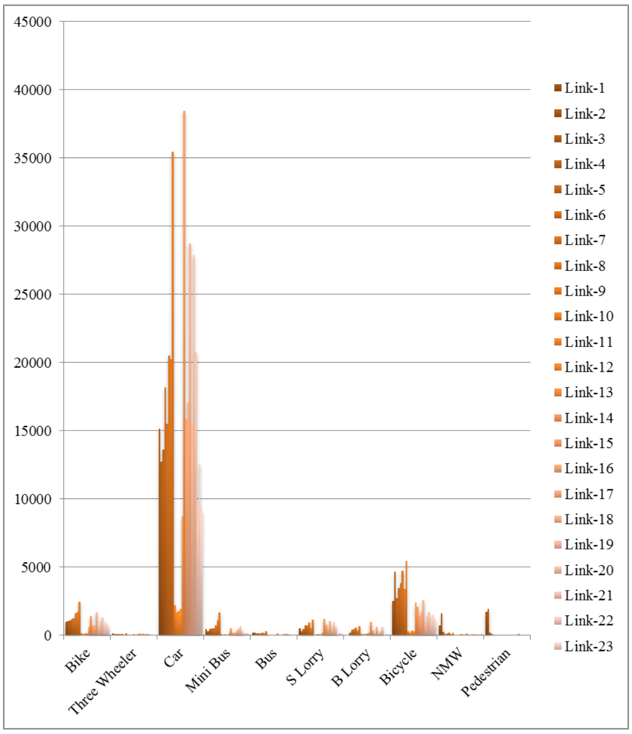

Fig.1.2 Vehicle types share in traffic stream (Field survey, 2013)

While developed countries are trying to reduce car dependency on the back of low carbon objectives, the ownership and the use of private cars in urban areas of Kabul city is increasing dramatically. Fig.1.2 depicts the share of vehicle types in the traffic stream during six hour survey, which declares the highest share of passenger car, followed by bicycle. Also, the city is lack of public transport (mass transit), which can play an important role in the reduction of emissions throughout the city.

Vehicle emissions and air quality data are not currently available from the government. However, a project of the Asian Development Bank (ADB) in Kabul and two other provinces performed a comprehensive assessment of emissions from different sources.

The assessment indicates that the majority of sources of air pollution in Kabul city are from mobile sources. Fig.1.3 shows the sources of air pollution throughout the Kabul city.

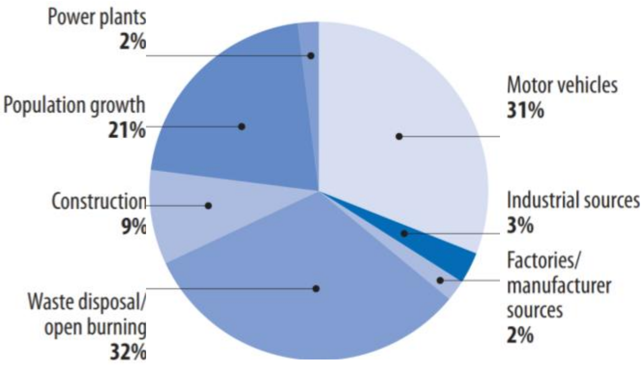

Fig.1.3 Sources of Air Pollution (source: ADB 2006b)

The ADB and the National Environmental Protection Agency (NEPA) also explored the impact of air pollution on residents of Kabul city by conducting a public perception survey in 2005 of 17 districts. The result of the survey is summarized in Fig.1.4.

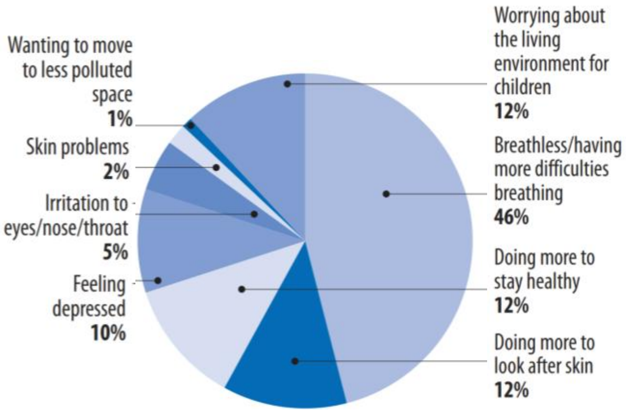

Fig.1.4 Impact of air pollution on residents of Kabul city (source: ADB 2006b)

1.1 Objectives

Kabul's unique challenges due to right-of-way encroachment by vendors, lack of signing and road strip, the existence of multiple modes sharing the roadway, which causes long travel times, and production of large amounts of CO_2 emissions need lots of efforts and researches to make comprehensive transportation plans, in order to reduce the time delay, fuel consumption and CO_2 emissions which really deteriorate the quality of life of Kabul residents and the environment. Thus, the objective of this study is to explore the distribution and the underlying the factors causing travel time delay which directly affects the production of CO_2 emissions, to contribute to Kabul's transportation studies, and to pave the road for future and further studies. Also this study will be beneficial in the transportation planning process for Kabul city.

This paper is organized in six sections Section 2 summarizes the characteristics of transportation in Kabul city. Section 3 describes the survey design and data collection process. Section 4 describes the key findings from the survey and this study. Section 5 describes the CO_2 emissions measurement and model estimation. Finally, Section 6 presents conclusions and suggestions for future studies.

2. TRANSPORTATION CHARACTERISTICES

Japan International Cooperation Agency (JICA) conducted the study for the development of the master plan for the Kabul Metropolitan Area (KMA) in 2008. This study was conducted by person trip (PT) survey in the KMA. The PT survey covered 50,000 households, which was representing 1% of the total households. This survey outlined that the total number of trips in a day related to Kabul city in 2008 is 3.35 million trips, which includes 1.02 million of on foot trips within the Kabul city. Trips by vehicles moving inside the City are 2.12 million.

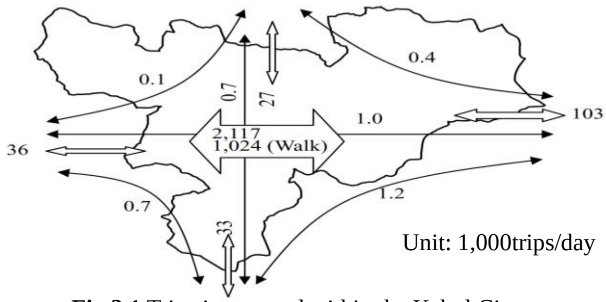

Fig.2.1 Trips in, out and within the Kabul City

(source: JICA)

Trip generation and attraction is mostly concentrated in the central part of the Kabul city Fig.2.2, shows the concentration of private and governmental organizations and employment opportunities in the area, on the other hand it indicates the unbalanced development of the Kabul city and less population presence due to limited employment opportunities in other areas.

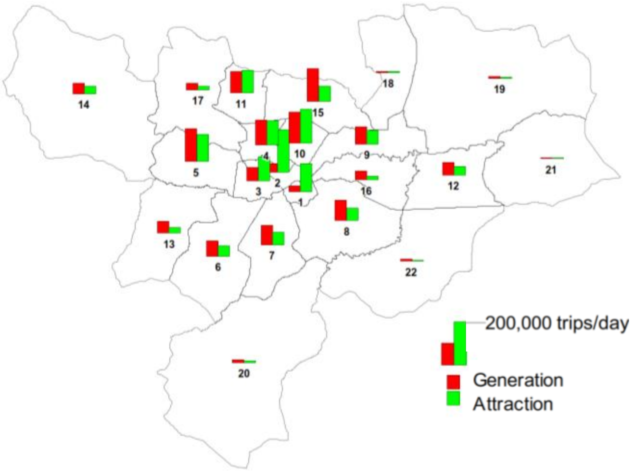

Fig.2.2 Trip Generation and Attraction (source: JICA)

The concentration of trips to the central part of the Kabul city make the roadways to experience a huge number of trips, traffic volume and more contribution to the long travel times and of course a significant contribution in the production of CO_2 emissions in the city. Fig.2.3 depicts the distribution of trips by all purposes within the Kabul city.

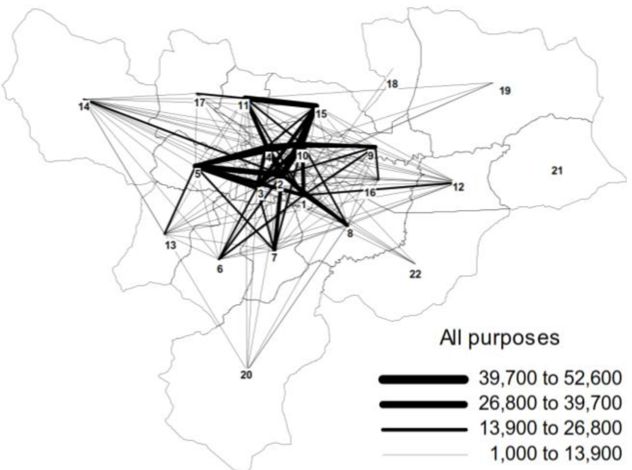

Fig.2.3 Trip Distribution (source: JICA)

3. SURVEY AND DATA COLLECTION

The main objective of this research is to explore the basic relationship between travel time and traffic volume for Kabul city. In this study, 23 links of the main corridor are selected of the main corridor. These 23 links are located in different parts of Kabul city, and connected to residential, educational, and commercial areas. Moreover, the selected links include different types of roads. Several time elements (months of the year, days of the week, and time of day) have been considered in establishing the scope for travel time and volume data collection activities. Thus, April and May, Sunday to Wednesday are commonly considered as an average condition of the traffic stream. During this survey traffic was counted six hours per link and each hour was divided into four time segments as follows:

Table.3.1 Survey Periods

Morning		
06:00 to 07:00	**07:00 to 08:00**	**08:00 to 09:00**
1. 06:00- 06:20	1. 07:20- 07:20	1. 08:00- 08:20
2. 06:20- 06:40	2. 07:20- 07:40	2. 08:20- 08:40
3. 06:40- 07:00	3. 07:40- 08:00	3. 08:40- 09:00

Noon	Evening	
12:20- 01:20	**03:40 to 04:40**	**04:40 to 05:40**
1. 12:20- 12:40	1. 03:40- 04:00	1. 04:40- 05:00
2. 12:40- 01:00	2. 04:00- 04:20	2. 05:00- 05:20
3. 01:00- 01:20	3. 04:20- 04:40	3. 05:20- 05:40

For the study of traffic flow, traffic count survey was implemented six hours per link by using Videography mostly at intersections. In terms of travel time survey the test vehicle technique has been used. The test vehicle technique has three different test vehicle driving styles (Average car, Floating car, and Maximum car). Since the inherent difficulties of keeping track of passed and passing vehicles in high traffic volume conditions are exits, therefore a hybrid of the floating car and average car driving styles have been used in this study.

During this survey a set of data (variables) have been collected, and are listed below:

- ✓ Directional traffic flow
- ✓ Directional travel time
- ✓ Free flow travel time
- ✓ Link dimensions, and
- ✓ Road condition

Furthermore the presence of illegal roadside parking and on-street occupancy through the links were also collected.

4. CHARACTERISTICS OF TRAFFIC FLOW IN KABUL CITY

4.1 Travel Time – Flow Relationships

Fig.4.1 demonstrates the relationships between travel time per kilometer in seconds and traffic volume in pcu per lane.

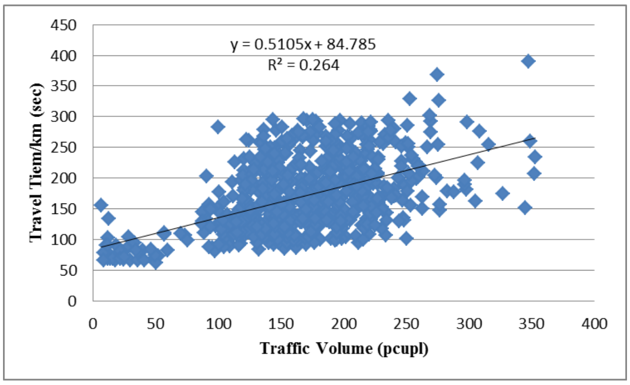

Fig.4.1 Travel Time – Flow Relationship (Field survey, 2013)

It indicates the relationships between travel time and traffic volume. The rate of change of travel time is 0.5105 from the function of changes in traffic volume by regression equation. The level of significance R^2 = 0.264 declares that travel time is not only affected by traffic volume, but there are also some other factors affecting travel time and will be considered in CO_2 emissions model estimation.

5. CO_2 EMISSIONS MEASUREMENT AND MODEL

5.1 CO_2 emissions measurement

The amount of CO_2 emissions can be adopted as proxy to quantify the energy cost of each trip. CO_2 is one of the main causes of environmental pollutions, global warming and the consequent climate change. It is primarily caused by the combustion of gasoline fuels (Steed 1990), and this is directly related to the travel time, thus the long travel times causes more energy being consumed and more amount of CO_2 will be emitted. Moreover, there are several models exiting in the literature (Stead 1999, Oguchi et al. 2002, Davis et al. 2005) that can be used for the estimation of CO_2 emissions of vehicles. Amongst these models, Stead's model (1999) is the simplest that only considers the travel length, whereas Davis' model (2005) is the most complex as it adopts the binning technology with consideration of both the micro-working conditions of vehicles and the surrounding environmental factors like wind direction and road slope. Since CO_2 emissions is directly affected by travel time and travel distance and the Oguchi's model considers these factors, and hence, it seems appropriate for collected data. Therefore In this study the Oguchi's model is adopted.

This model considers the speed change in terms of acceleration or deceleration, total travel time, and total travel length Eq.5.1, and it is specifically used for the gasoline-powered vehicles.

$$E(trip) = K_C * (0.3T + 0.028D + 0.056 \sum_{i=2}^{n} \delta * (v_i^2 - v_{i-1}^2))$$

(Eq.5.1)

Where E is the estimated CO_2 emissions amount (Kg), K_C is the CO_2 emissions coefficient with the value of 0.002322, T is the total travel time (second), D is the total travel time length (meter), v_i is the velocity at location i (m/s), n is the number of locations in the trip, and δ is an indicator with value 1 ($v_i > v_{i-1}$) or 0 ($v_i <= v_{i-1}$).

In this study, some assumptions have been made that considers all the vehicles in traffic stream are gasoline-powered vehicle, and (v_i<=v_{i-1}), hence the indicator value equals to 0, therefore the CO_2 emissions model takes the form as Eq.5.2.

$$E(trip) = K_C * (0.3T + 0.028D) \quad \textbf{(Eq.5.2)}$$

In the Eq.5.2 the variables are modified as, *E* is the amount of CO_2 emissions per kilometer (gr), *T* is the travel time per kilometer, and also *D* is travel length (kilometer). This model has been used to estimate the amount of CO_2 emissions emitted by each trip per kilometer.

5.2 Impact of different variables

Table.5.1 illustrates the relationship between CO_2 emissions by each trip per kilometer and some selected variables that affect the CO_2 emissions.

Table.5.1 Correlation coefficient (Field survey, 2013)

	Correlation				
	CO_2 Emission/km				
	TV(pcupl)	%EA	NoSMV	RC	DNI
Pearson Correlation	0.514**	-0.367**	0.225**	-0.122**	0.164**
Sig. (2-tailed)	0.000	0.000	0.000	0.002	0.000
N	651	651	651	651	651
**. Correlation is significant at the 0.01 level (2-tailed).					

The explanatory variables that are considered to affect the CO_2 emissions per kilometer are; Traffic Volume (TV pcupl), the percentage of area of the link which is available to traffic flow, or the percentage of Effective Area (%EA), Number of Slow Moving Vehicles (NoSMV), Road Condition (RC) is considered as dummy variable, where the value of 1 is considered for good condition and 0 for bad condition, and Damage Near Intersection (DNI) is also considered as dummy variable with the value of 1 for the existence of damage and 0 for not damaged.

According to the correlation coefficients Table.5.1 all variables seem to be statistically significant. The changes of traffic volume (pcupl) have the highest coefficient of correlation (0.514) which is also highly significant. The correlation coefficient between CO_2 emissions per kilometer and percentage of effective area and road condition is negative; it indicates that the increase in effective area of a link with a good condition will decrease the amount CO_2 emissions.

5.3 CO_2 emissions model

To explore the CO_2 emissions per kilometer of link throughout the Kabul city, we use multiple regressions to build the model Eq.5.3.

$$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{3i} + \beta_4 x_{4i} + \beta_5 x_{5i} \quad \textbf{(Eq.5.3)}$$

Where: y is the dependent variable (CO_2 emissions), x_1, x_2, x_3, x_4 and x_5 are the predictors or independent variable and β_0, β_1, β_2, β_3, β_4 and β_5 are the parameters. Table.5.2 depicts the estimated parameters for the CO_2 emissions model. In terms of regression equation the rate of change of CO_2 emissions is controlled by explanatory variables of Traffic Volume by rate of 0.306, Percentage of effective area with -3.958, Road condition with rate of -15.417, and Damage near intersection and NoSMV each by rate of 25.319 and 0.044 which moderately acceptable with the R^2 value of 40%.

Table.5.2 CO_2 emissions estimation model (Field survey,

Variables	Parameter	R	R^2	t	sig.
Constant	463.656	0.631	0.40	11.007	0.000
TV(pcupl)	0.306			13.787	0.000
%EA	-3.958			-9.593	0.000
RC	-15.417			-3.273	0.001
DNI	25.319			5.808	0.000
NoSMV	0.044			1.539	0.124

6. CONCLUSIONS

This study explores the CO_2 emissions per kilometer which induced by each trip throughout the Kabul city.

It is clear that travel time has a significant effect on CO_2 emissions. Overall, even small changes in travel time can have significant effect. Therefore the CO_2 emissions are affected by the variables affected to travel time.

After analyzing the CO_2 emissions and exploring the relationships between CO_2 emissions and explanatory variables, it can be concluded precisely that elimination of on-street occupancy, in other words obtaining higher percentage of effective area, repairing of the roads having bad condition and intersection damages, will balance the traffic volume, and also will be significantly reduce the amount of CO_2 emissions. The existence of old cars and different type of vehicles is another challenging issue which requires further studies.

The recent studies on Kabul's transportation and the collected data by author on April and May, 2013 pave the road for more precise research on Kabul transportation problem and will contribute for a comprehensive planning to Kabul's transportation.

The data that has been collected by the authors can be used to identify congested roadway segments. Those roadway segments could be studied further to determine the root cause of the congestion, whether it is operational issues, recurring incidents, insufficient capacity, or other causes, and additional studies could be conducted to identify potential roadway improvements. The collected data could also be used to prioritize Transportation Improvements Program (TIP) within the Kabul city.

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